2017

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International Journal of Advanced Biotechnology and Research (IJBR)
ISSN 0976-2612, Online ISSN 2278–599X,
Vol-8, Issue-1, 2017, 305-314
http://www.bipublication.com

Research Article

Assessing the efficiency of different sustainable farming practices in reducing the environmental impacts caused by Aquaculture

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RUNNING HEAD: ASSESSING THE EFFICIENCY OF SUSTAINABLE FARMING PRACTICES

ABSTRACT:
Sustainability of aquaculture is achieved when aquaculture farming systems are capable of preserving the natural resource base and involves an institutional change to the environment by the attainment and continued satisfaction for present and future generations. Sustainable farming practices produce sufficient aquaculture output to satisfy the seafood demand while not burdening the environment more. The potentiality and efficiency of different sustainable aqua farming practices in reducing anthropogenic impacts to the environment by aquaculture are assessed in this paper. Polyculture is mostly adopted by small-scale rural farmers as it requires low entry barrier and help in income diversification. The input of inorganic fertilizer in polyculturing should be also minimized, replacing with efficient nitrogen use for better sustainability means. While green technologies like Recirculating aquaculture system (RASs), designed integrated aquaculture-wetland ecosystem (AWE) and Bioflocs involves more complicated interactions between the water treatment, the feed, and the fish. Hence, results with more variables in results and higher cost of adoption. However, the implications are much wider, not limited no nutrient uptake, salinity and pH, but the removal of total dissolved solids. While GIS analysis could serve as a guide for the site-selection in minimizing environmental impacts and preventing aquaculture failure. Different approaches should be adopted to fulfil different needs depending on the species being cultured and adjacent environmental context.

Keywords: Sustainable aquaculture, IMTA, IAA, RAS, AWE, Bioflocs, GIS Site selection

INTRODUCTION

In early 1900's, fishing is a profession carried out by the coastal villagers who have the strategic location for accessing open sea fisheries and are equipped with strong fishing skills. Moreover, they have the knowledge inherited from the previous generations. Traditional fishing has been providing fishermen income from simple market transactions, and most importantly, serve as the main source of their food. In fact, in recent centuries, the old fisheries concept has been overturning from self-sufficiency to commercialized venture in conjunction to burgeoning human population. Since then, the annual fish production and global per capita consumption of fish have been reported with remarkable growth rate. Vigorous modernization and industrial evolution are the two main contributors attributing to the proliferated fishing sector. While the minor factors that contributed are the technological advancement, sustained fish production and higher per capita income. With the progress of the time, the fishing fleets are now well furnished with processing facilities, fish scouting airplanes, cold storage and acoustic technology to locate the fish school in Open Ocean at various depths precisely. FAO (2014) reported that the catch from capture fisheries rose approximately three-fold from 20 million tons to 60 million tons between the years 1950-1970 alone, and hit 90 million tons in year 2012.

Despite, the technological improvement has brought fisheries sector to ever new triumph, the industry soon under fire for responsibility of excessive over-exploitation of marine fishing grounds and severe habitat destruction. Human's understanding of their impact on environment soon underwent drastic revolution after the significant trilogy tragedies: the collapse of Peruvian anchovy fishery, diminishing of North Atlantic demersal fisheries and Canada Cod. The abundance of Cod stocks in Canada went critic to the extent that the government has no other choice but announced a two years ban for commercial fishing off Labrador and Newfoundland.

However, in 1997-98 when the fisheries were partially reopened, the data are still discouraging, causing the fisheries closure in 2003 until further notice. Eight years later, the stock was reported with a 34% growth, as well as positive results for other marine invertebrate population sharing the habitat.

Due to the limited marine fisheries resources, governments and private sectors around the world started to run fish farming to act as a momentary solution for marine seafood shortage. Nonetheless, every solution breeds new problems. Controversy arose again when unsustainable intensive aquaculture being practiced, which resulted in more severe environmental degradation, not to mention other wicked problems like 'fishing down farming up' which involved harvesting of pelagic planktivorous in serving as live feed for the high trophic level of farmed organisms. Instead, being an answer to combat overfishing crisis, some might even argue that aquaculture is worsening the issue by putting more reliance on the wild fish stock. In fact, the highlight underpinning here is whether aquaculture is done in a sustainable way.

The sustainability of aquaculture can be analysed through the a few correlated dimension of production technology, social and economic consequences and environmental influences **(**Shi *et al.*, 2013).

One could be considered as sustainable aquaculture when it is capable of preserving the natural resource base and involves an institutional change to the environment by the attainment and continued satisfaction for present and future generations. Thus, sustainable aquaculture is the only way to produce sufficient output in order to satisfy the ever-growing seafood demand from world population, while not burdening the environment more.

This paper discusses about, the potentiality of employing different sustainable aqua farming practices in reducing anthropogenic impacts to the environment.

Polyculture

Integrated Multi-trophic Aquaculture (IMTA)

Sustainable aquaculture comes in many different forms, the simplest one would be the polyculture. According to Troell *et al.* (2009), Integrated Multi-trophic aquaculture (IMTA) is the integrated culture that combines fed aquaculture species (fish, shrimp etc) with inorganic extractive species lie seaweed, and organic particulate extractive aquaculture species like shellfish with the aims to purify its effluent to self-support the recycling purposes and increase the economic benefits by increasing the production. Currently, China has launched IMTA at an industrial scale whereas the rest of the participating nations are still in their scaling up stages. In China, Integrated

Mangrove-aquaculture System (IMAS) was established in 2002 which uses mangrove species *Aegiceras corniculatum* to filter aquaculture ponds through the nutrient uptake by the plant (Peng *et al.*, 2013). Peng *et al.* (2013) have proven that IMAS effectively halt mangrove degradation and restore abandoned aquaculture ponds through replantation.

It also partially resolves the incompatibility between coastal wetland conservation and the construction of aquaculture ponds under its long-term sustainable concept. In the demonstration study carried out at the Pearl River Estuary, the ratio of energy flow between the detrivory and herbivory food chains were successfully reduced from 4.4:1 to 3.9:1, which showed that more energy flow within the food chain from organic detritus. While in Sanggou (Sungo) Bay, a suspended cultivation research was conducted by Shi *et al.* (2013) who compared the ecological and economic benefits of kelps monoculture, scallop monoculture and polyculture of both (IMTA). The results of Shi *et al.* (2013) revealed that IMTA has better performance in terms of environmental sustainability index (ESI), net present value (NPV), the benefit to cost ratio and relative coefficient (RC), which overall indicated it as the highest sustainability.

In this case, scallops ingest the organic materials and micro-organisms whereas kelps absorb the organic and inorganic wastes from scallops in the pond. Due to its polyculture concept, IMTA productivity significantly maximizes the economic benefit and at the meantime, genuinely known as 'economy of integration' (Whitmarsh *et al.*, 2006). On the other hand, IMTA projects are also adopted in Canada, where kelps and blue mussels were cultivated in Atlantic salmon farms; and in Zhangzidao Island, China, where scallop, sea cucumber, abalone, and arkshell are cultivated in the same area (Troell *et al.*, 2009).

At present, IMTA was considered as a matured, and well-studied program. However, it lacks in the worldwide adoption. This might be related to our current discouraging economic circumstances, and by unsteady future price trend as IMTA are susceptible to price fluctuations (Whitmarsh *et al.*, 2006). As long as the prices are stabilized and the profit-cost fall within estimation, IMTA would be attractive and definitely worthwhile for investment. The benefits and gains of IMTA should be greatly publicized for more cultivators to learn more about this benefitting technology and later consider adopting them.

Integrated Aquaculture-Agriculture (IAA)

The ideology of polyculture can be brought forward to another extent, which is the integrated aquaculture-agriculture by concurrent or sequential linkages between these two farming activities (Murshed-E-Jahan & Pemsl, 2011). Again, this system emphasis the recycling of resources and synergy among the components by using agriculture by-products including livestock and poultry manure and convert them into high-grade fish protein (Murshed-E-Jahan & Pemsl, 2011). The system works in such a way that crop residues serve as feeds for fish while fish pond sediments and water flow back as crop fertilizers and for soil irrigation purposes (Murshed-E-Jahan & Pemsl, 2011). IAA is not a recent innovation but a phenomenon that has existed in nature.

For instance, in flooded rice field of Bangladesh, living aquatic resources (LARs) occur naturally in the ponds. However, their abundance is so small that they are only enough for farmer's household. While IAA involves stocking of selected species of fish, molluscs and crustaceans intentionally to boost the protein production from agriculture farms, it also amplifies the water storage capacity and enhance the soil fertility (Prein, 2002 and Murshed-E-Jahan & Pemsl, 2011). According to Ewoukem *et al.* (2012), it is important that the selected species should be of the lower trophic level in the ecosystem so that it can diminish deadlocks frequency of the water by stirring up and re-suspend the pond sediments as they feed and filter them. Consequently, they could further intensify the nutrient assimilation.

It is not difficult to spot one IAA in Asia as this system has traditionally practiced over here (Schneider *et al.*, 2005). Countries like Malaysia are gifted with rich land resources which are suitable for agriculture. Yet, their agriculture industry is underdeveloped and agriculture farmers are often located at the bottom of their nation's economic pyramid (Alsagoff, Clonts & Jolly, 1990). Thus under the government intention, low priced food fish, tilapia was brought to the rural rice farm and later the poultry field with the aim of impeding inflation and encouraging balanced economic growth (Alsagoff, Clonts & Jolly, 1990). While, for Mekong Delta, IAA was practiced in orchard regions with the low-input fish farming system and the medium to high input fish farming is practiced in paddy fields (Nhan *et al.*, 2007). However, Phong *et al.* (2010) reported that for superior nutrient efficiency in farms, the application of fertilizer has to be cautiously maintained as over usage of the fertilizers will hamper the related processes. In a nutshell, Nhan *et al.* (2007) have found the IAA received quite overwhelming acceptance rate among farmers in Mekong Delta.

Unlike, the Recirculating Aquaculture System (RASs) and other modern green technologies, integrated polyculture, no matter IMTA or IAA, often hold low risk as it helps in product and income diversification (Prein, 2002). Hence, the adoption rate is relatively higher for this lower entry system, especially among small-scale rural farmers in developing countries (Prein, 2002). Despite polyculture can afford many pros with lower cost and knowledge, it most likely will lose its pros once intensified in large scale commercial operation as product maximization were often put as prime concern over the other environmental issues (Prein, 2002).

Additionally, for small-scale operators in the rural areas to meet the nutritional requirement in order to enhance enterprise diversity and production, extra labor is needed, which might act as a huge obstacle for them. To ensure the overall sustainability degree of the system, the input of inorganic fertilizer for agriculture purposes should be minimized, and replaced with efficient usage of nitrogen (Phong *et al*., 2011).

Green technology

Recirculating aquaculture system (RASs)

Sustainability of aquaculture farm can be acquired by the assistance of external mechanisms, such as treatment of farm water with chemical means, careful selection of site with expertise knowledge and introduction of organism that prompt sustainability but not commercial values.

Recirculating aquaculture system (RASs) is an integrated land-based aquatic system where part of the water undergo both mechanical and biological treatment before reused to cut down overall energy and water consumption, besides mitigating the nutrients present in the effluents before discharging it into the environment (Zhang *et al.*, 2011).

RAS basically have farming ponds with in-built flow-through systems, which are linked by culvert pipes across the pond banks fixed at a slope of 50% to ensure mixing of the upper stratum with the lower one so as to promote the passive aeration (Zhang *et al.*, 2011). Nutrient effluents that are discharged from traditional aquaculture farming in open cages and ponds has been given lots of attention, as it might invite uncontrollable pollution, such as eutrophication (Schneider *et al.*, 2005).

When compared to the traditional farming, RASs offers improved waste management and nutrient recycling technologies, through effective water purification process to achieve sterilization means and better disease management (Schneider *et al.*, 2005). In terms of biosecurity, RASs profoundly eliminates the risk of escapees that may results in genetic and ecological contamination of wild stock (Wik *et al.*, 2009). To date, RASs have proliferated to vast range of species, from freshwater to brackish water, involving hatchery or fingerling to grow-out production (Zhang *et al.*, 2011).

This system should be widely introduced to aquaculture, especially for those organism with low tolerance to water quality fluctuations in typical subtropical areas, as it provides better environmental conditions control all year-round (Wik *et al*., 2009). Under well-controlled water parameter, which achievable with RASs, fish found with better feeding conversion rate (FCR) and improved feeding efficiency. Thus, bringing back benefits to the aquatic shareholders with more profits.

Unfortunately, due to the complicated interactions between the water treatment, the feed, and the fish, RASs involved time lag to show its actual biology and effectiveness (Wik *et al*., 2009). The tedious and costly process hinder the development and adoption of RASs. Farmers need to comprise some degree investment before the system reach the robust and competitive stage (Wik *et al*., 2009). Therefore, the application of RAS is still limited to only a few regions, for example for the freshwater African catfish and eel production in Netherlands and trout ongoing semi-closed traditional farming system in Denmark (Martins *et. al*., 2010). The Dutch RAS are typically indoor, closed systems (Martins *et al*., 2009) for freshwater production of African catfish and eel. All the maintenance and production operations are completely automated and monitored by a centralised software system designed in-house. Only one operator is required to manage the entire facility.

The Danish model trout farms are outdoor, semi-closed systems and RAS allows fingerlings to be moved from their tanks through a pump system, graded according to size, vaccinated, and then sorted and segregated into other tanks, entirely by machinery (Jokumsen *et al*., 2009). In France RAS farms based on the danish model, was operated at a water refreshment rate of 9000 L/Kg feed/day (Roque d'Orbcastel *et al*., 2009).

In Norway a production of 85 million smolts in RAS is foreseen (Del campo *et al*., 2010). Southeast Asian countries contributes about seventeen per cent of the global aquaculture production and aquaculture plays a substantial role in these countries economy, food supply and rural livelihoods.

But there is lack of space and lot of environmental restrictions pose limitations towards the further expansion of conventional aquaculture. These countries are moving towards Recirculating Aquaculture System (RAS) developments as it is one of the ways to produce fishes in an environmentally sustainable way. Countries like Singapore, Malaysia, Indonesia and Vietnam have highly attractive markets and investing more in RAS. While, in Singapore Apollo aquarium has started a pilot plant that is producing groupers through RAS.

Designed integrated aquaculture-wetland ecosystem (AWE)

Studied by Costa-Pierce (1998), AWE is a system connecting polyculture aquaculture ponds with in-pond aquatic plant system, solar energy aeration system and an artificial wetland for food production and inorganic nitrogen removal from tertiary-treated wastewater. It functions as a natural fourth layer of wastewater treatment to reproduce usable water for agriculture purposes (Costa-Pierce, 1998).

The wetland contains halophytic macrophytes which support the decomposition of suspended solids and reduces the biological oxygen demand via the leaf canopy it generates (Buhmann & Papenbrock, 2013). Macrophytes are capable in absorbing large amount of inorganic nutrients and heavy metal from stabilization ponds as their growth requirements (Pescod, 1992).

However, the uptake rates of nutrients and metals vary widely for different macrophytes species. In Buhmann & Papenbrock (2013)'s research, they conclude that *Digitaria bicornis* and *Typha angustifolia* are the two macrophytes species equipped with the best purifying effects in saline wastewater.

The design of the AWE during experimental studies of Costa Pierce in 1998 was shown in Fig 1.

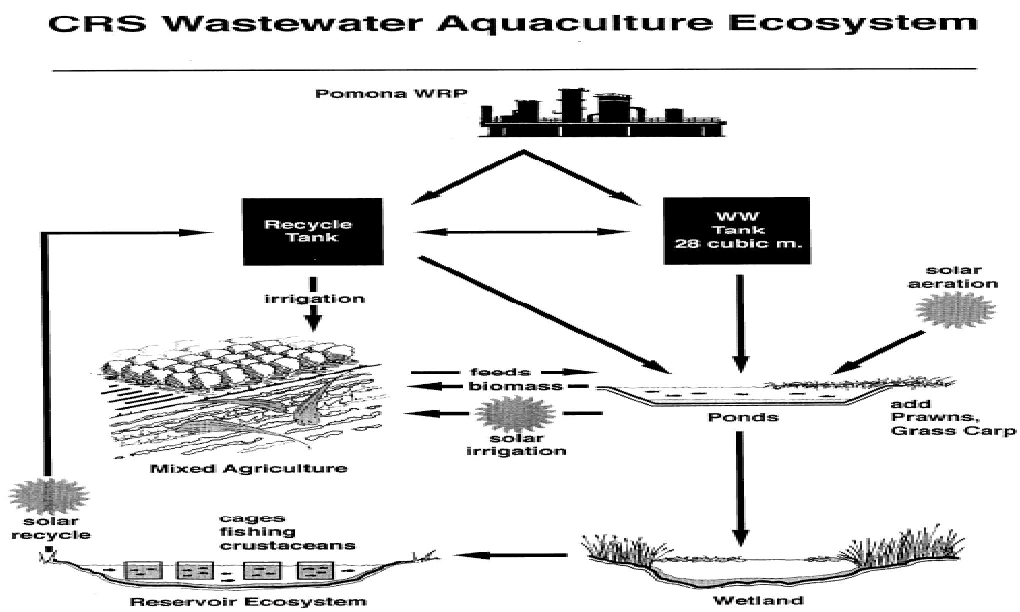

Figure 1: Aquaculture-wetland ecosystem (AWE) design in experimentation in Pomona tertiary treatment plant (Costa-Pierce, 1998).

The tertiary-treated wastewater before subjecting to the AWE treatment has a low inorganic N: O ratio due to its nitrogenous content. The situation is even worse for shrimp pond effluents which often have extreme amounts of nutrient filled-suspended solids. All these would invite disastrous event such as hyper-eutrophication of the nearby ecosystem and later contribute to more wicked problems. In the preliminary study of Costa-Pierce (1998) work, the result showed that when wastewater was passed through AWE it has significantly low concentration of ammonia and nitrate. Mean pH stabilized at a average of 6.30 which is originally 10.0.

As mentioned earlier, the cleaning effect of halophytes depends on the species which determines its absorption and precipitation capabilities. Thus, different wastewater sources have to match with different biofiltering wetlands (Buhmann & Papenbrock, 2013). Nonetheless, Buhmann & Papenbrock (2013) suggested that combination of different types of constructed wetland would sustain a complete cleaning processes to overcome the shortcoming of single type wetland.

AWE filtering treatment has now reached out from agriculture and aquaculture means, to wider application: industrial purposes. Saiyood *et. al.* (2012), found that halophytic plant species, especially *S.maritima* is suitable for remediating total dissolved solid (TDS) by the removal of dissolvent and decreasing of salinity, pH and electrical conductivity, from contaminated plastic industrial effluent. Overall, this technology is significantly beneficial to those inland regions which have limited freshwater resources, like Singapore, the United States, some parts of India, and Malaysia as it promotes wastewater recycling, help filling the demand from non-portable use. However, more detail research is essential to further understand in terms of the carrying capacities, nutrient cycle's efficiency, and bioaccumulation of metals in and output in order to diverse the AWE utilization, even to portable uses.

Bioflocs

Recent research has developed biofloc technology, which is a new method to mitigate water quality in aquaculture pond by balancing the carbon and nitrogen in the system. Extra carbon is added to the system through external sources or elevated feed with carbon content (Crab *et al.*, 2012). It results in boosting nitrogen uptake for the bacterial growth to a higher rate than the natural nitrification process. Compared to the conventional techniques such as biofilters, bioflocs would be more strategic as it is able to work even in the worst condition when organic matter and biological oxygen demand is high. Another advantage of biofloc technology is that it able to instantly upcycles through closing the nutrient loop, instead of ‘downcycling’ or exchanging of the water like what other system usually did. Thus, the water quality would not be further deteriorated and consequently total amount of nutrients discharged would be reduced. Another interesting point of biofloc is that it fights pathogenic bacteria in aquaculture (Defoirdt *et al.*, 2004). Bioflocs grown on glycerol were able to protect gnotobiotic brine shrimp *Artemia franciscana* against pathogen *vibrio harveyi* and that beneficial effect was likely due to interference with the pathogens quorum sensing system (Defoirdt *et al.*, 2004).

Besides that, *Litopenaeus vannamei* microbial flakes together with bacteria genus Bacillus sp. are also capable in inhibiting the pathogens and the antagonistic activity of pathogen *Vibrio alginolyticus* in super intensive culture system of marine shrimp (Ferreira *et. al.*, 2015). With the help of microbial flakes, *Bacillus licheniformis* effectively decrease the concentration of the pathogen in water. Ferreira *et. al.* (2015) stated that immune system of marine shrimp could also be strengthened by adding *Bacillus spp.* in the diet. In short, bioflocs is a great tool that serve as probiotics or as biocontrol for the haphazard mishandling of antibiotics in aquaculture.

GIS Site Selection

Though holistic aquaculture management is essential for environmental protection, site selection for farming should not be neglected as well. For meeting sustainability standards, relatively harmless or well mitigated aquaculture starts from the early planning stages (Longdill, Healy & Black, 2008). Poor site selection cause stress to the adjacent ecosystems, the farming species itself and affects its growth, productions and ultimately leads to aquaculture failure (Longdill, Healy & Black, 2008). With the help of advanced technology, Geographic Information System (GIS) based model evaluates different sites to locate the areas that are suitable for a species-specific farming (Radiarta, Saitoh & Miyazono, 2008). Longdill, Healy & Black’s (2008) reported that GIS evaluation is not limited to biophysical, ecological or social dimension within the locations but also together consider the social-economic aspect, to achieve results with holistic approach. Hence, the suggestion given by GIS would rather favor higher sustainability potential on a long run.

For instance, in Funka Bay, Japan, GIS was used to detect the areas which suit for hanging culture of Japanese scallop, *Mizuhopecten yessoensis*. Within the 1038 km^2 potential area, 22% of the area was labeled as constraint areas as it was located too near to the municipal waste treatment plant and river mouth.

It was suggested to avoid this site in order to minimize the disgruntle from neighbors and public (Radiarta, Saitoh & Miyazono, 2008). While in Companigonj Upazila of Noakhali, Bangladesh, GIS together with remote sensing (RS) are employed to evaluate the land suitability modelling for giant prawn, *Macrobrachium rosenbergii* farming (Hossain & Das, 2010). Hossain and Das (2010) reported that only 52% of the 22,999 ha land area is most suitable for prawn farming, while the remaining 45% is moderately suitable and 3% is not suitable.

The 3% of land is mostly made up of mangrove forest with permeable soils which uptakes relatively more water and may incurred higher irrigation cost and lower sustainable efficiency. This technology has also been used in New Zealand to detect most suitable and most importantly, sustainable locations for suspended mussel, *Perna canaliculus* cultivation (Longdill, Healy & Black, 2008).

GIS analysis should not be the absolute answer but serve as a guide for the decision as GIS could only afford estimation not accurate figures.

There are also other criteria that are overlooked by GIS which might also have to be included in the decision-making processes, such as tourism, coastal recreation, conservation and fishing operation (Radiarta, Saitoh & Miyazono, 2008). GIS could be facilitated for coastal planners and management scheme for best resources optimization (Radiarta, Saitoh & Miyazono, 2008; Longdill, Healy & Black, 2008).

CONCLUSION

There is no one-size that fit all solution or best technology that suits in every aquafarming system. Different approaches should be adopted to fulfil the different needs depending on the culture species and adjacent environmental context.

For example, polyculturing is suitable for extensive rural aquaculture as it does not require much of the technical knowledge and able to increase the production value at the same time. Whereas, for intensive closed aquaculture farm, green technologies can be considered, as it might incur amicable investment and long term operating cost.

Immatureness of technology, low awareness on sustainability, insufficient expansion services, poor farm management and fear of accepting new concepts were the drawbacks associated with sustainable aquaculture in rural as well as developed region (Nhan *et al.*, 2007).

It is utmost important to have sustainable aquaculture, not for the extra value added to the existing industry, but to ensure at least the discharge to adjacent water bodies are safe and harmless to the environment.

All the concepts discussed earlier are literally an enhancement on top of our normal aquaculture practices.

In order to hit the goal of sustainability, the basic healthy practices of aquaculture have to be continuously abided.

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